11th International Workshop on Computational Electronics
TU Wien, 25-27 May 2006

Electron Transport in Self-Switching Nano-Diode

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INTRODUCTION

Self-switching Diode (SSD) is a new type of planar nano-diode, which is based on a nano-channel with a broken geometric symmetry [1]. It has been shown to operate in the Terahertz regime at room temperature. In this work, Monte Carlo (MC) simulations were performed and the mechanism of the diode-like characteristics and the existence of threshold voltages were explained.

MONTE CARLO MODEL

An SSD with the geometry shown in Fig. 1 is considered here and a semi-classical ensemble MC method, self-consistently coupled with Poisson equation, is used [2]. For simplicity, not all layers in the InGaAs/InAlAs heterostructure are included in the simulation. The 2D MC simulation is carried out only on the InGaAs layer which contains the two-dimensional electron gas and hence determines the characteristic of the device. In order to take into account the effect of carriers injection from the δ-doped layer, a virtual doping (without impurity scattering), $N_v=10^{17}cm^{-3}$, is assigned to the InGaAs layer. For comparison, the effect of the surface states at the semiconductor-air interfaces originated by the etching process is ignored initially and then added in the simulations.

RESULT AND DISCUSSION

Figs. 2&3 show the electron distributions inside the SSD at applied voltages *V*=-2.0V and +2.0V, respectively. As expected, the electron density inside the channel increases for *V*=+2.0V and decreases for *V*=-2.0V. In these two cases, the average velocities of the electrons in the channel are similar because of the same voltage drop, yet the currents are very different, resulting in the diode-like characteristic in Fig. 5(a). The different electron densities in the channel come from the different electron distributions outside the channel. As shown in Figs. 2&3, the asymmetric boundary induces electron accumulation and depletion on the left and right sides, respectively, for *V*=+2.0V and inversely for *V*=-2.0V. The different distributions cause a different transverse electric potential (see Fig. 4) which eventually yields different electron densities. At low biases, the above difference can be ignored, so the device works like an ohmic resistance with no threshold voltage (see Fig. 5(a)). In a more realistic case, a negative surface charge density, σ, is assigned to the semiconductor-air interfaces to simulate the effect of surface states. Fig. 6 shows the distributions of electric potential inside the SSD with $\sigma=0.3\times10^{12}cm^{-2}$ for *V*=+2.0V, 0.0V and -2.0V, which are similar to those in the references [3, 4]. Comparing Figs. 4&6, one can find that the electric potential in the vicinity of the channel is reduced by the surface states and a barrier of a height of about 1V arises. Such a barrier yields a threshold voltage of about 1.2V (see Fig. 5(b)).

CONCLUSION

The diode-like characteristics of SSD are simulated based on the different electron distributions caused by asymmetric boundary. The existence of the threshold voltage is found to be a result of the lateral depletion by the surface states at the semiconductor-air interfaces.

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ISBN 3-901578-16-1

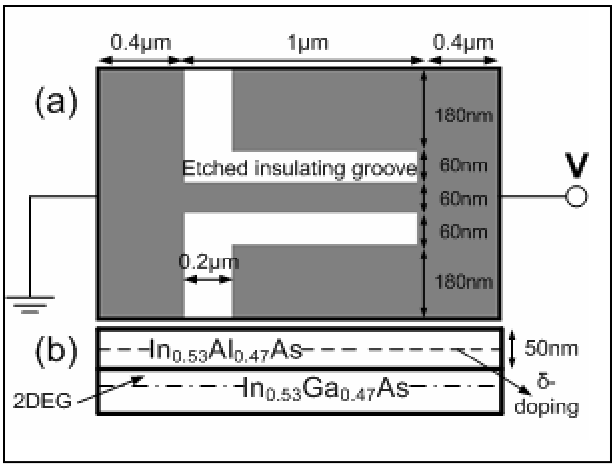

Fig.1.Top view of the simulated SSD (a) and lateral view of a real structure (b).

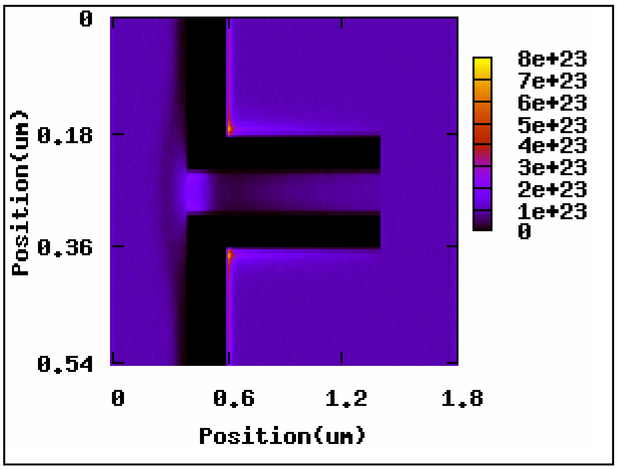

Fig.2. Spatial distribution of the electron density inside the SSD assuming no surface states for V= -2 V.

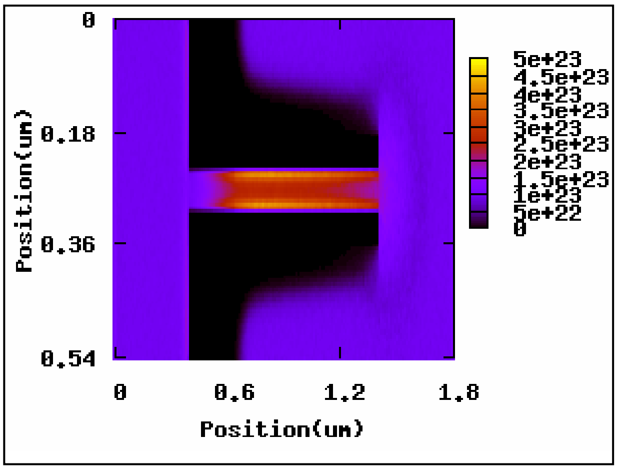

Fig.3. Spatial distribution of the electron density inside the SSD at V=+2 V assuming no surface states.

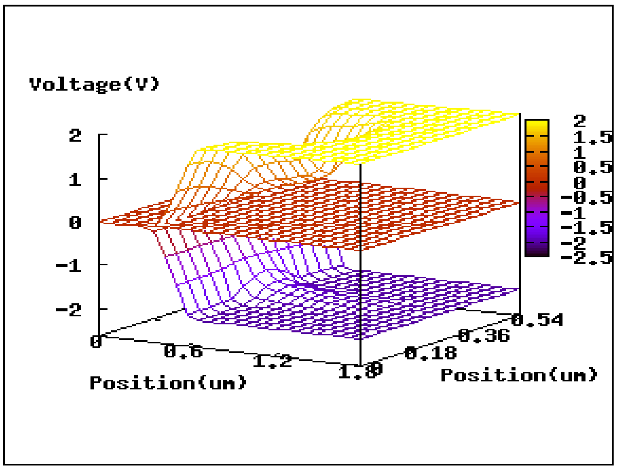

Fig.4. Distribution of electric potential inside the SSD assuming no surface states for V=+2.0 V, 0.0 V and -2.0 V

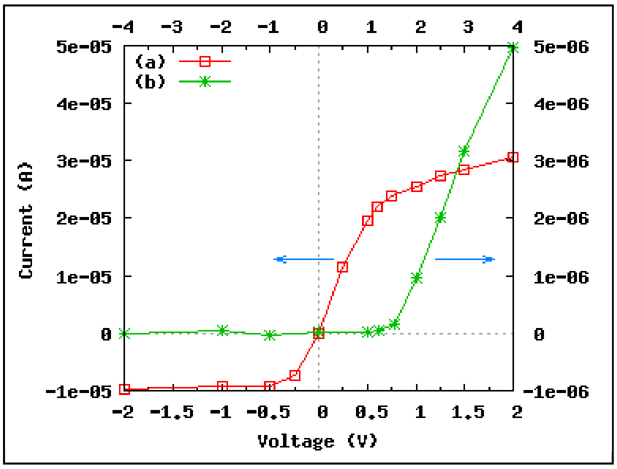

Fig.5. I-V characteristics of the SSD assuming no surface states (a) and with surface states density $\sigma=0.3\times10^{-12}cm^{-2}$ (b)

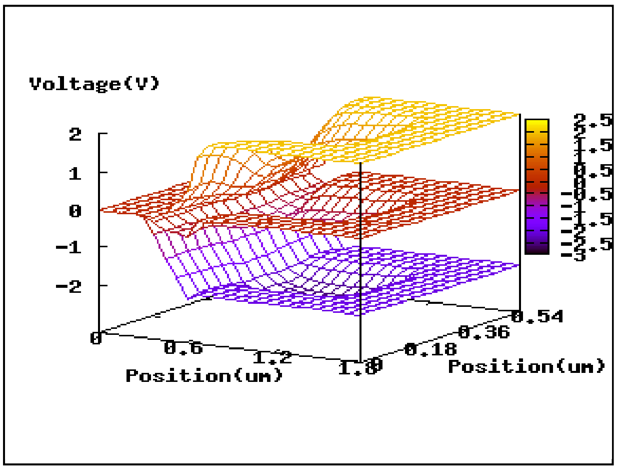

Fig.6. Distribution of electric potential inside the SSD with $\sigma=0.3\times10^{-12}$ cm^{-2} for V=+2.0 V, 0.0 V and -2.0 V.